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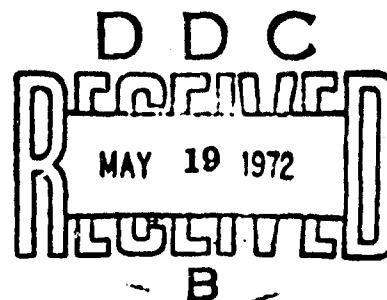
# NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20034



## NEW DIMENSIONS FOR NAVAL CATAMARANS

by  
Robert M. Stevens



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May 1972

Report 3830

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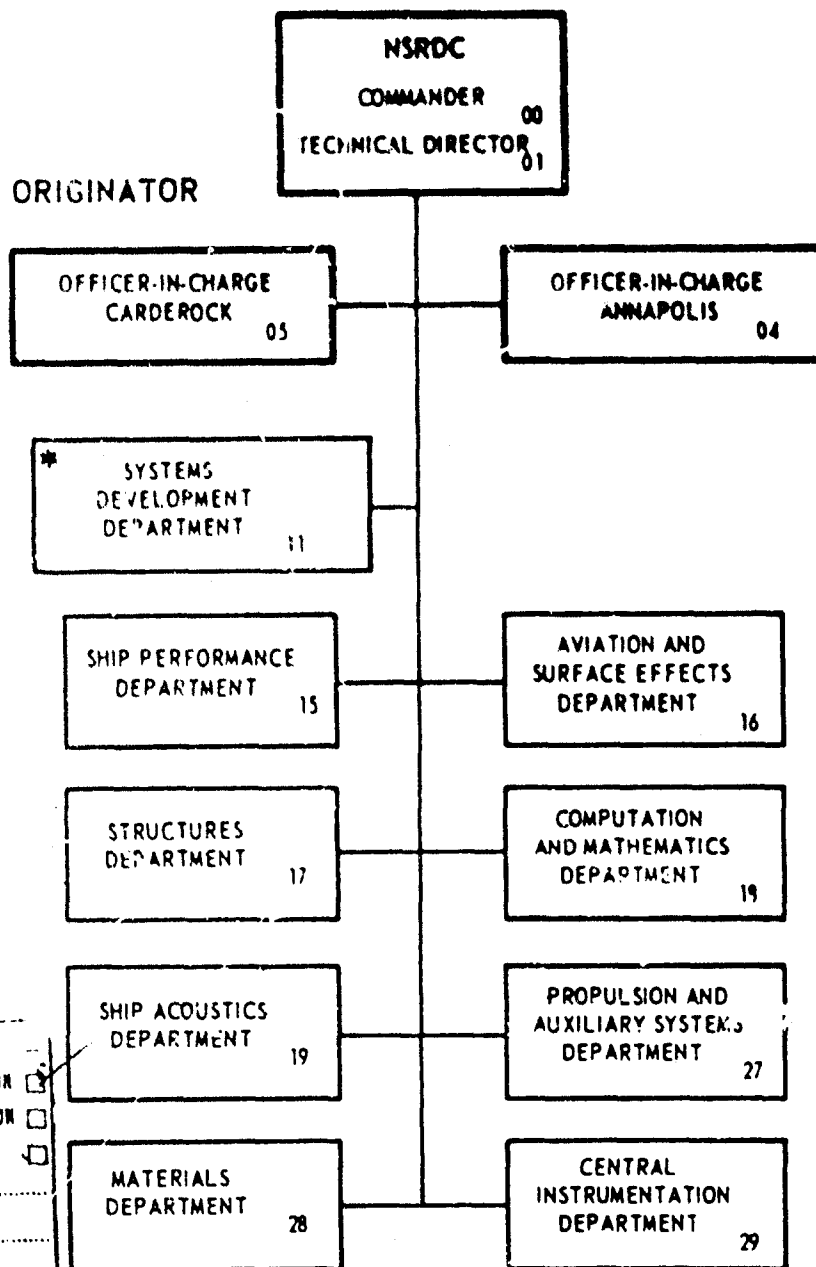
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## ABSTRACT

Since the design of the ASR, significant advances have been made in catamaran technology which center around two new developments: (1) completion of new hydrodynamic procedures for underwater hull design and (2) emergence of the low-waterplane (LWP) catamaran as a promising new form. Application of these new hydrodynamic procedures to the LWP form has dramatically reduced wavemaking properties to very low values. Total resistance is shown to be comparable to monohull resistance at moderate Froude numbers and superior in higher regions.

Seakeeping experiments have confirmed the excellent motion qualities of the LWP catamaran. Data are presented which compare pitch, heave, and roll of the LWP catamaran with conventional catamaran forms and a monohull CVA. New approaches are needed to the design of efficient, lightweight steel structures. Efforts in this area are described, and a design example is presented. Structural weight densities for hull, strut, and bridge are included and compared with familiar monohulls.

Additional topics include space, weight, and propulsion machinery considerations. The report concludes with a synthesis of LWP catamaran qualities and application to a current Navy ship concept.

## ADMINISTRATIVE INFORMATION

This report describes results accumulated during the period FY70 through mid-FY72. Funding for this work has been provided principally by the in-house independent exploratory development program of the Naval Ship Research and Development Center (NSRDC) under Task Area ZFXX412001, and by the Naval Ship Systems Command (NAVSHIPS) Ship Feasibility, under Task Area SF35411001.

## INTRODUCTION

Until very recently catamarans were often considered second best to monohull surface ships because their resistance characteristics were poorer for most applications. Their roll stability was better but accelerations were often too great, and other motions were about the same. Moreover the excessive structural weight would increase both initial and maintenance costs and degrade performance. Despite these shortcomings, however, the great deck area offered by the catamaran continued to interest the Navy for

specific applications. Consequently, catamaran research has continued in an effort to find solutions to problem areas while preserving favorable qualities.

A 1970 paper by Bond<sup>1</sup> summarized the (then) current state of catamaran technology. Since that time, several developments have altered the achievable performance characteristics of catamarans and have had a significant impact on the rate at which catamaran technology has been advancing. Especially important were the identification of the low-waterplane catamaran as a promising new hydrodynamic form and the verification of new analytic procedures for designing the associated hydrodynamic bodies for minimal wavemaking drag. This report will focus on these and related developments and will present some early and recently developed data for promising advanced catamaran forms. To make the data more meaningful, they have been compared to data for monohulls and for various members of the catamaran family. Such comparisons may be valid only in a qualitative sense because equivalence may not have been established between the things compared. The conventional parameters used to compare monohull ships (displacement, length, speed, etc.) are not always meaningful for catamarans, and the broad technical data base for the newer forms is inadequate to allow for totally valid comparisons. Nevertheless, general trends which show departure from experience can be indicated, and these may stimulate interest in future commercial and military applications. As research and development efforts provide more information, it will be possible to provide more definitive comparisons of ship qualities.

#### CATAMARAN FORMS

The term "catamaran" includes a family of surface ships that have two hulls aligned side by side and joined by a bridging structure. Ship configurations such as the TRISEC, DUPLUS, and Semisubmerged Ship are included in the family, as are most existing or conventional catamarans.

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1. Bond, J.R., Commander, USN, "Catamarans--Dream or Reality," Naval Engineers Journal (Jun 1970).

Conventional catamarans (Concats) are made up of two more-or-less standard displacement hulls. The two hulls may be symmetric or asymmetric; they may have centerline camber to reduce wavemaking resistance and flow buildup between the hulls. Conventional catamarans have full waterplanes and stern configurations adapted from monohull practice. Lines for the ASR catamaran shown in Figure 1 illustrate a typical Concat form. The full waterplane gives Concats motion properties that are generally similar to those of monohulls and, except for roll, their motions are quite similar. The combination of full waterplane and wide hull spacing leads to large transverse waterplane inertia, high metacentric heights, large roll restoring moments, and short roll periods.

The names "modified catamaran," TRISEC, and Semisubmerged Ship ( $S^3$ ) all refer to members of the low-waterplane (LWP) catamaran family. The LWP form is a derivative of the conventional form in which the waterplane is thinned and buoyancy is redistributed downward into a fully submerged lower hull. A strut, sized to provide adequate static stability as a minimum requirement, connects each lower hull to the above-water platform. Because it is necessary to reduce the surface wavemaking potential of the lower hull through reasonably deep submergence, the draft of an LWP catamaran will be larger than that of a comparable conventional catamaran or monohull.

Figure 2 illustrates an LWP catamaran in its simplest configuration. In his description of the TRISEC concept,<sup>2</sup> Leopold illustrated possible variations on the basic form which included removing the amidships portion of the strut and substituting two lower hulls (each with a propulsor) in place of the one. Another variation of the low-waterplane catamaran is the Dutch workshop DUPLUS which has horizontal stabilizer foils at the forward and after ends.

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2. Leopold, R., "A New Hull Form for High-Speed Volume--Limited Displacement-Type Ships," Trans. of Spring Meeting, SNAME (1969).

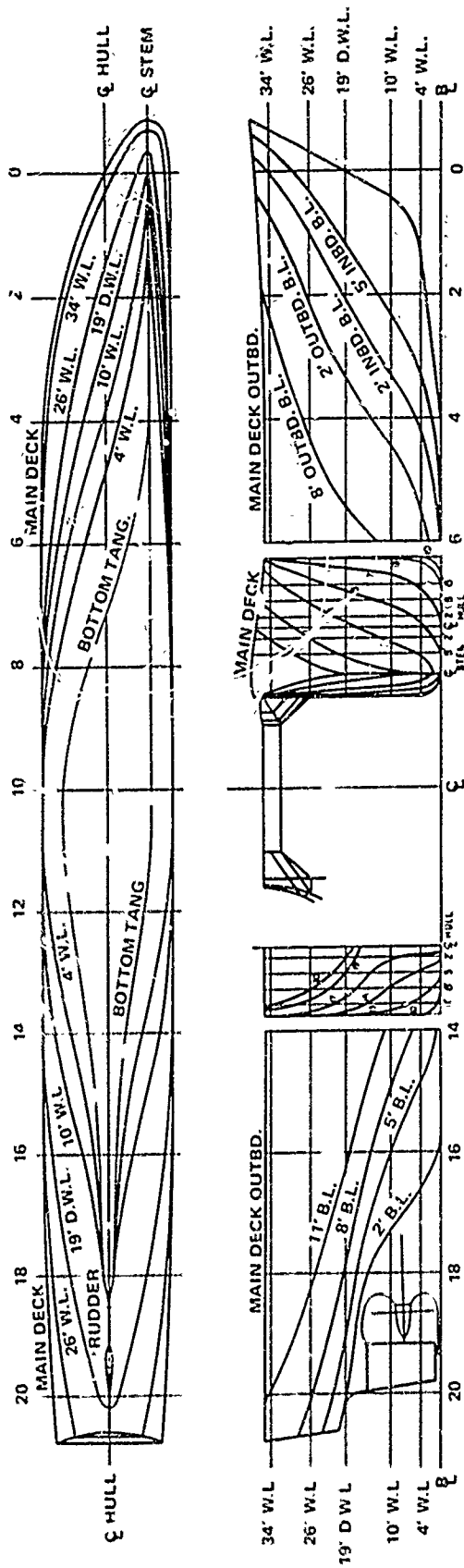


Figure 1 - Lines for ASR-21

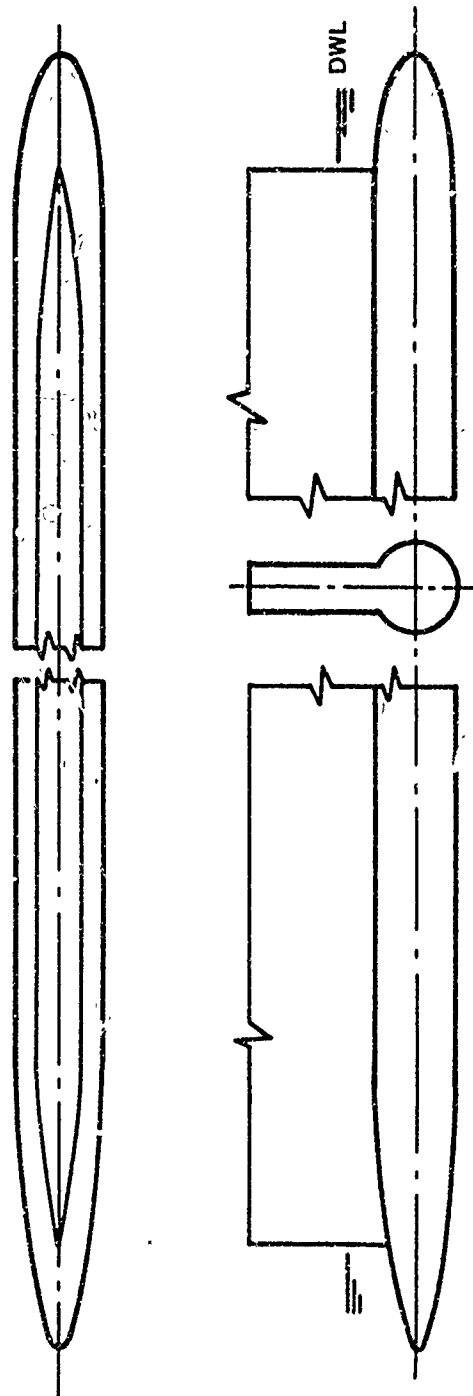


Figure 2 - Simple LWP Catamaran Demihull

An important aspect of this analytical approach is to design for flow interaction between parts of a submerged body. By this method, the strut and lower hull of an LWP catamaran are designed together so that the waves generated by each are mutually cancelling over the desired speed range. The effect is to produce a drag that is substantially less than the sum of the drags of each body alone. Good results are obtainable, however, only if the lower hull alone is a low-drag hydrodynamic body.

The method has been applied successfully to a small number of catamaran designs. Figure 4 illustrates the general form of an improved LWP large displacement hull designed to operate at  $V/\sqrt{L} = 1.1$  knots/ft<sup>1/2</sup> by the Pien method.\* Quadruple-screw propulsion was required and so the stern section was configured to accommodate four screws. More recent work has been directed toward the development of a high-speed form ( $V/\sqrt{L} = 2$  knots/ft<sup>1/2</sup>) of the LWP configuration. Analytic estimates have been made of the drag properties of the hull and validating tank test results will be available in the spring of 1972.

## RESISTANCE AND PROPULSION

### WETTED AREA AND FRICTIONAL RESISTANCE

Ship resistance is considered to consist of frictional drag, pressure drag, and wavemaking drag. The frictional part is a function of the friction coefficient (which depends on the Reynolds number),\*\* the wetted area, and the second power of speed. The principal differences in frictional resistances between monohulls and catamarans will stem from differences in Reynolds number and wetted area. Since most ships operate in a narrow Reynolds number region over which the frictional coefficient

---

\*  $V/\sqrt{L}$  is the speed-length ratio, where ship speed is in knots and ship length in feet.

\*\* Reynolds number  $Re = VL/\nu$ , where  $V$  is the ship speed,  $L$  is the hull length, and  $\nu$  is the kinematic viscosity ( $1.2817 \times 10^{-5}$  ft<sup>2</sup>/sec for sea water at a temperature of 59 F).

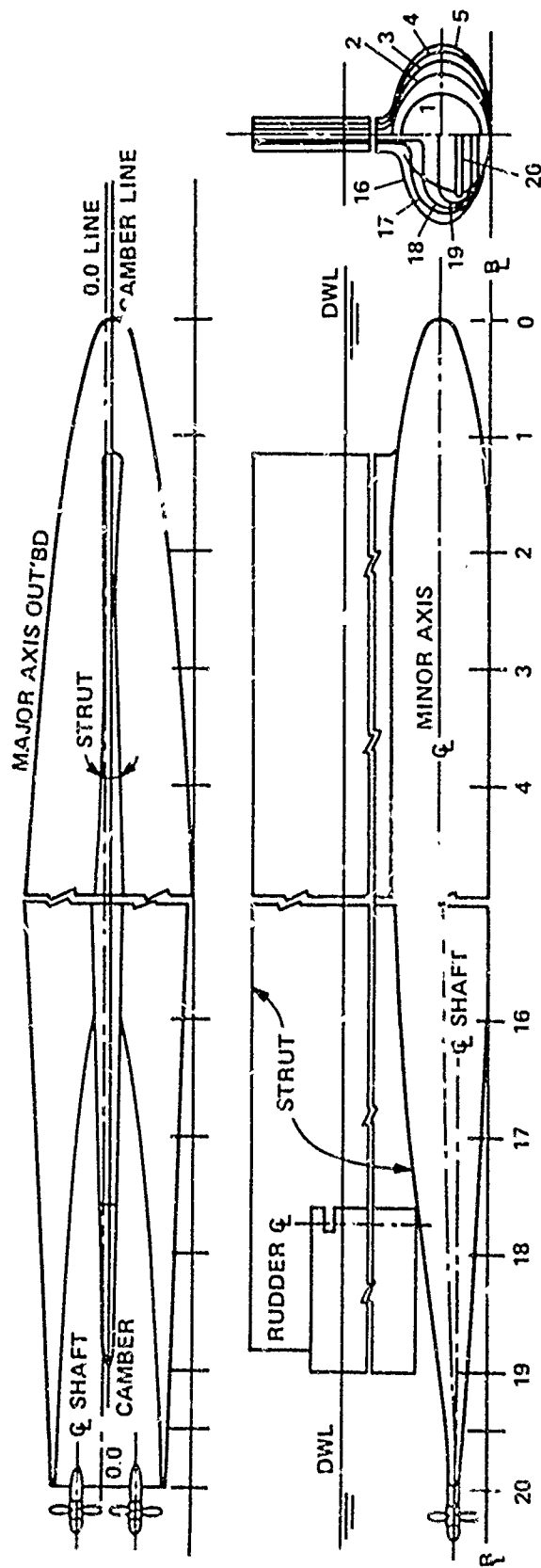


Figure 4 - Lines for Improved LWP Catamaran Demihull

varies very little, length variations between monohulls and catamarans will have only minor effects on the frictional component of resistance.

The effects of wetted area are much more pronounced. Because of their twin hulls, all catamarans have greater wetted area and therefore higher frictional resistance than monohulls of equivalent displacement. Table 1 compares typical wetted surfaces by using the parameter  $S/\sqrt{\Delta L}$ .<sup>\*</sup> In this comparison total wetted surface area and total displacement have been used.

TABLE 1 - WETTED SURFACE COMPARISON

Ship Type	$S/\sqrt{\Delta L}/(S/\sqrt{\Delta L})_{\text{Monohull}}$
Monohull	1.0
Conventional Catamaran	1.4
Low-Waterplane Catamaran	2.3
Semisubmerged Catamaran	2.3

The table shows that for an equivalent displacement-length product, the wetted area of a low-waterplane catamaran will be more than twice that of a monohull; its frictional resistance will also be approximately double for equal speeds. If an LWP catamaran is to be competitive with a monohull on a resistance basis, then total resistance must be equal or better. This cannot occur at low speeds where the frictional drag is a major part of the total. The catamaran may always be at a disadvantage here because of its increased surface area. Wavemaking drag of monohulls increases rapidly with speed and is a major part of the total resistance at high Froude numbers.<sup>\*\*</sup> If catamarans can show an advantage in wavemaking resistance over monohulls at high Froude numbers, then it may be possible

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<sup>\*</sup>  $S/\sqrt{\Delta L}$  is the wetted surface parameter in which S is the wetted surface in feet<sup>2</sup>, L is the ship length in feet, and  $\Delta$  is the displacement in long tons.

<sup>\*\*</sup> Froude number (non-dimensional) =  $v/\sqrt{gL}$ , where v is velocity, L is length, and g is the gravitational constant.

for the total resistance of the catamaran to be lower than that of a monohull. The greater the advantage, the lower the Froude number at which total resistance will be equal.

For LWP catamarans to be competitive at lower speeds, ways must be found to reduce their wetted area. Reductions in ship length, which cause area reductions, may be possible in certain applications; other applications may permit reduction of wetted area through reduction of strut length and draft and use of a multistrut (per side) configuration.

Interestingly enough, although these elementary resistance considerations have been well understood for Concats, most catamaran applications to date have involved low ship speeds where the resistance penalty has been great. Only recently has attention been given to operation at high Froude number and to the development of catamaran forms to operate there.

#### WAVEMAKING RESISTANCE

A review of the literature reveals that catamaran wavemaking resistance has not been well understood. Like a monohull, each demihull of a catamaran, produces surface wave patterns which vary with the form of the hull, with speed, and with draft and separation. The energy required to produce these disturbances must come from the propulsion of the hull, and these waves are manifestations of the wavemaking drag of the hull. At certain speeds, the wave trains from the demihulls of a catamaran reinforce each other between the hulls to produce sharp increases in wavemaking resistance; at other speeds, they cancel and diminish wavemaking resistance.

This effect is shown graphically in Figure 5 where the ratio of catamaran (hull pair) wavemaking coefficient/to single hull wavemaking coefficient is plotted as a function of speed. These data were derived from tank experiments on the simple LWP catamaran form and are neither typical of all catamarans nor of those designed analytically. Only illustration of the general effect is intended. Interference effects are evident in the towing tank where large standing wave patterns created by the model vary in amplitude and position with changes in hull speed and separation.



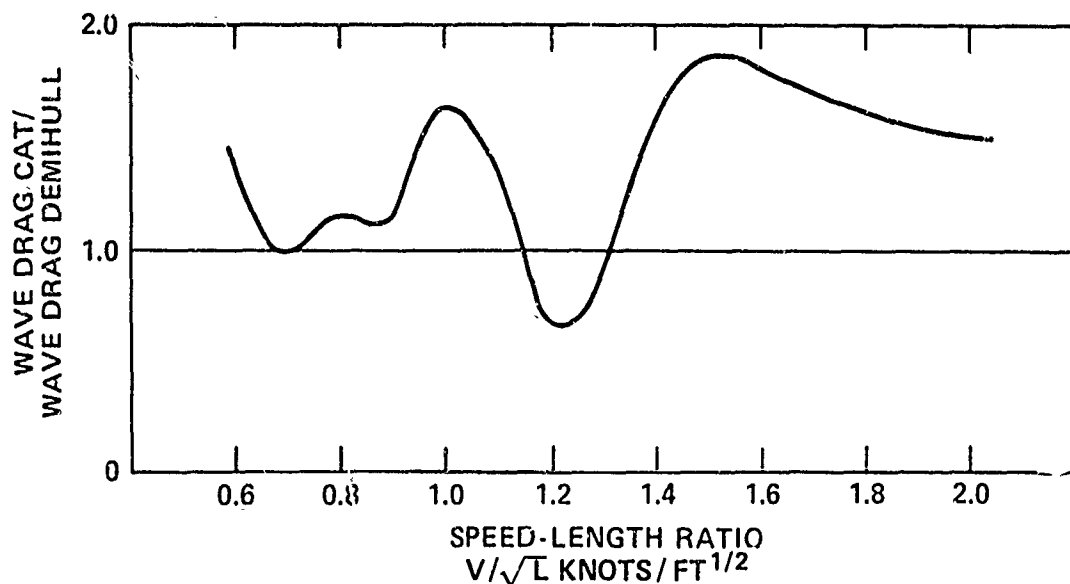


Figure 5 - Interference Factor--Simple LWP Catamaran

Low-waterplane catamarans, including the semisubmerged catamaran, exhibit still another kind of wave interference which has its origins in the independent wave systems of the lower hull and of the strut. When these two sections are designed without regard to wave interference effects, the kind of behavior illustrated in Figure 6 is likely to result. Data for this figure were derived from towing tests of a single hull of the simple LWP catamaran of Figure 2 (not designed for minimum wavemaking). The large humps and hollows in the resistance curve illustrate the reinforcement and cancellation of waves.

The Semisubmerged Ship ( $S^3$ ) illustrates still another wave interference phenomenon: mutual interference of wave systems of the forward and after struts. Experiments conducted at NSRDC on a 12-ft model have yielded the wavemaking characteristics shown in Figure 7. This model form was optimized for high speed ( $V/\sqrt{L} = 3$  knots/ft<sup>1/2</sup>) without particular regard for resistance characteristics at lower speeds. Wavemaking characteristics of the simple LWP catamaran are also included in this figure.

These results for  $S^3$  and simple LWP catamaran forms have been presented principally to provide a frame of reference against which to illustrate the gains that are possible through the application of techniques for minimization of wavemaking resistance. Such techniques have enabled an LWP catamaran to be designed (Figure 4) for operation at

$V/\sqrt{L} \approx 1.1$  knots/ft<sup>1/2</sup>, and its resistance properties have been verified by model tests. As shown in Figure 7, it exhibits good resistance qualities when compared with the  $S^3$  and simple LWP forms. The results demonstrate a low level of variation of residual drag as well as an absolute reduction in resistance throughout the speed range for which it was designed. Even with such dramatic reductions in wavemaking, however, this low-waterplane form continues to have higher total resistance than the monohull (see Figure 8) because of the greater wetted area and frictional component.

The real significance of these results is that they have validated the applicability of the analytical method for minimization and control of wavemaking. Work can now continue on adapting the LWP form and the analytical procedures to higher speed regions ( $V/\sqrt{L} \approx 2$  knots/ft<sup>1/2</sup>) where monohull wavemaking becomes prohibitive. The expected resistance properties of the high-speed LWP catamaran ship now being developed are

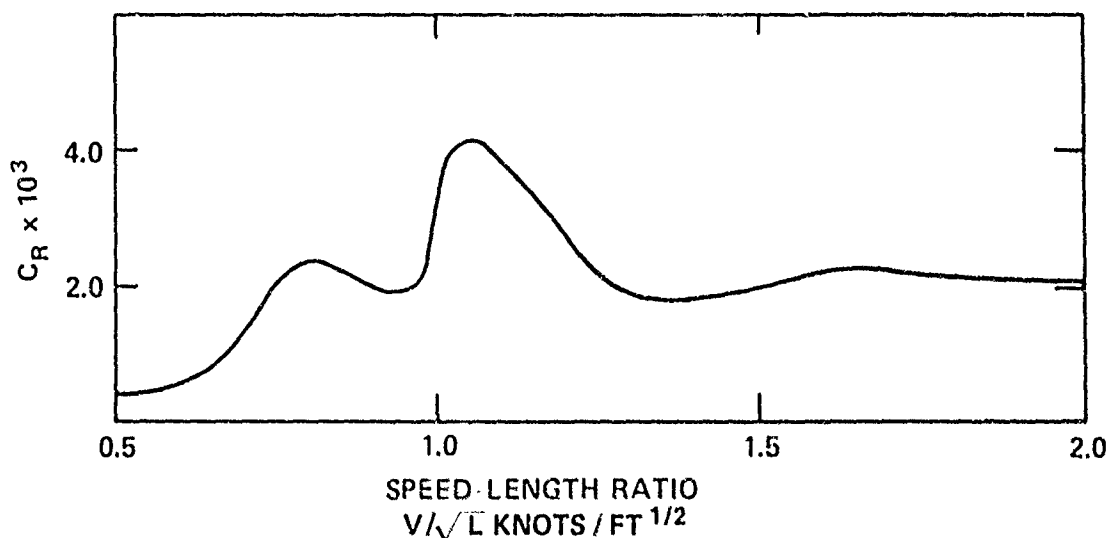


Figure 6 - Single Hull Wavemaking--Simple LWP Catamaran

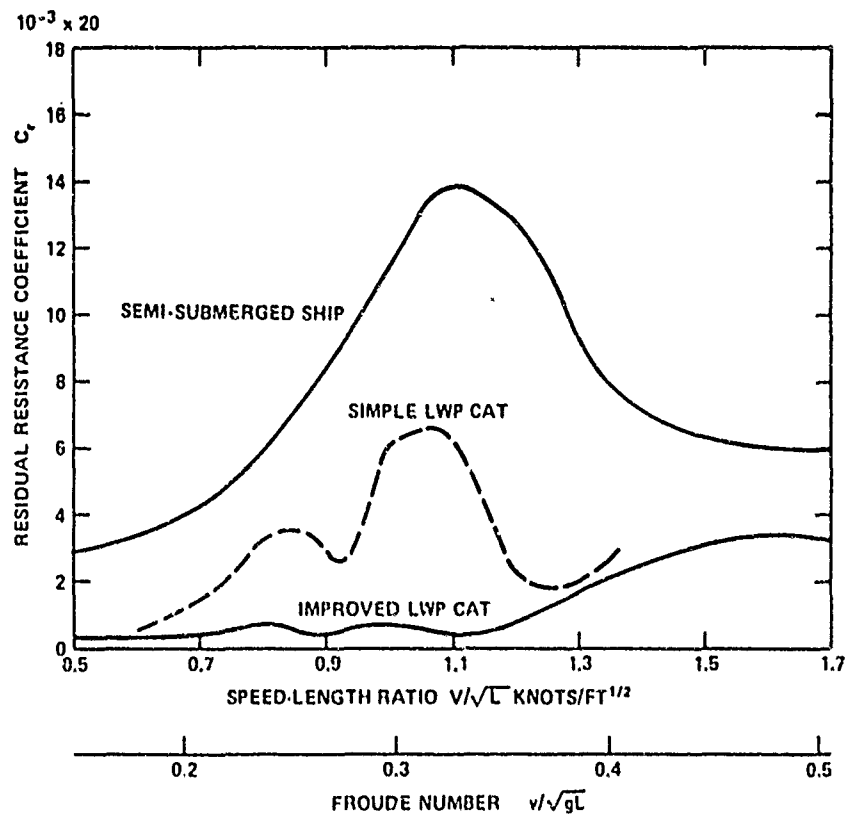


Figure 7 - Comparative Residual Resistance

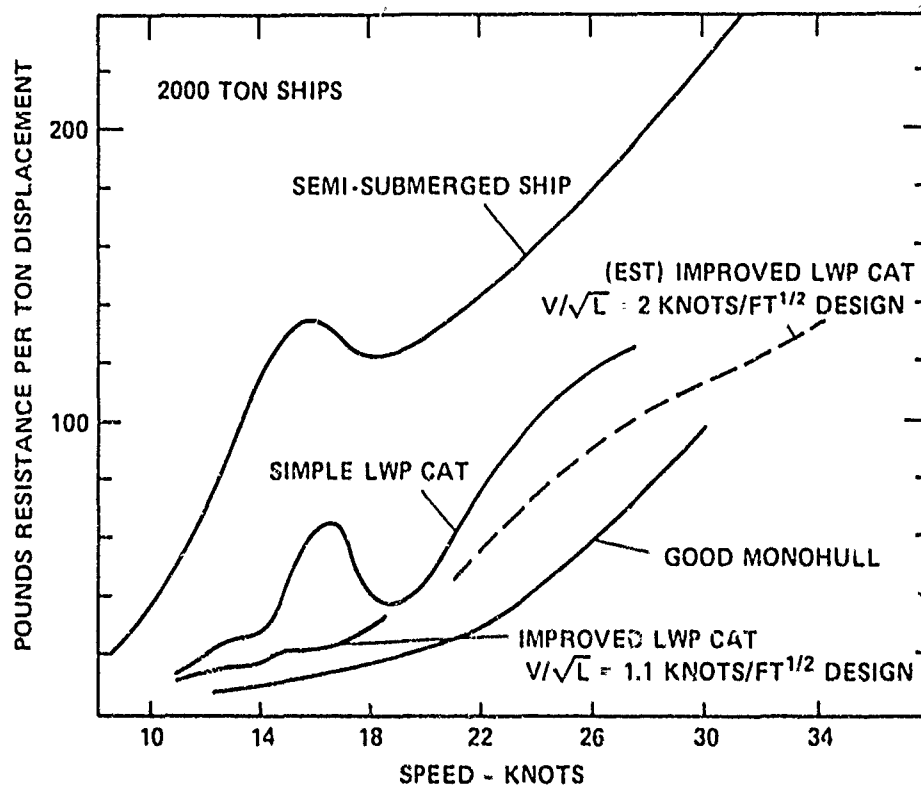


Figure 8 - Comparative Resistance

included in Figure 8. Following experimental verification of the analytic techniques in this region of speed-length ratio, developmental work will proceed to reduce the wetted surface, as might be obtained in shorter, larger diameter demihulls. The expectation is that ultimately the LWP catamaran can be designed to have resistance characteristics superior to those of an equivalent monohull at lower speeds than now predicted.

## PROPULSION

Most investigations conducted to date for catamaran propulsion systems have dealt with ships of conventional form. Propulsive coefficients derived from propulsion experiments have been rather low, and indeed lower than predicted. Medium-sized catamaran demihulls would each have a single-screw arrangement while the comparable monohull would necessarily have twin screws. The ship wake in the plane of the propeller should be more favorable for the catamaran, and better propulsive performance should result.

The expected improvements in propulsive characteristics have not been observed in model tests, however. Instead, propulsive coefficients for catamarans have been lower than values for the usual single-screw monohull. Unfavorable crossflow into the propeller plane of catamarans such as the ASR has been suggested as the reason for diminished performance, but this has not been confirmed experimentally.

A limited amount of propulsion data has been produced on the LWP forms. The unfavorable propulsive condition which can result from surface wave patterns was demonstrated in tests on the simple LWP form at a draft corresponding to one diameter submergence (to the keel of the hull) of the lower hull. In this instance, the surface wave that formed between the hulls placed the propellers in a trough, yielding an indeterminate propulsive coefficient. Ballasting to deeper draft produced movement of the trough, greater propeller submergence, and improved propulsive performance.

When propulsion tests were performed on the improved LWP catamaran at deeper draft, the resulting propulsive coefficient was well behaved.

Over the tested speed range, the propulsive efficiency for the quadruple-screw arrangement (twin screws for each hull), approximated values for monohulls with twin-screw propulsion.

One effect of the analytical procedure is to reduce crossflow into the propeller plane. If earlier opinions are correct (i.e., that propulsive efficiency is reduced by crossflow effects), then it should be possible to observe improvements in catamaran propulsive performance when wavemaking is minimized. Powering in waves should also be improved for the LWP form because of its more favorable motions. Resistance and propulsion experiments of a single-screw (per hull) high-speed LWP catamaran will be conducted in the near future and, hopefully, these experiments will verify the expected propulsion improvements.

#### SEA-INDUCED MOTIONS

Results of seakeeping studies in head waves are shown in Figures 9 and 10 for a number of catamaran forms. Rigid-body motions are given for the ASR catamaran, a simple LWP catamaran and, for comparison, a monohull CVA. All ships were of equal length. The curves were derived from regular wave tests in the NSRDC seakeeping facility. The more favorable pitch and heave response of the LWP catamaran in head seas is very evident. The rise of the response curves at  $\lambda/L = 2^*$  indicates the onset of a resonance which, unfortunately, was not fully explored. Up to the point of resonance, however, both heave and pitch were minimal and considerably less than for monohulls. No experimental data are available on the phasing of these motions, but even with the most stringent assumption, good platform motions can be expected up through moderate sea states. Response for the semisubmerged hull are not included in these figures; however, the motions for this ship are similar to, or better than, those of the simple LWP catamaran.

An improved LWP catamaran (designed by the analytical method) had considerably less waterplane area than the simple LWP catamaran. Motion

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\* Ratio of wave length to ship length.

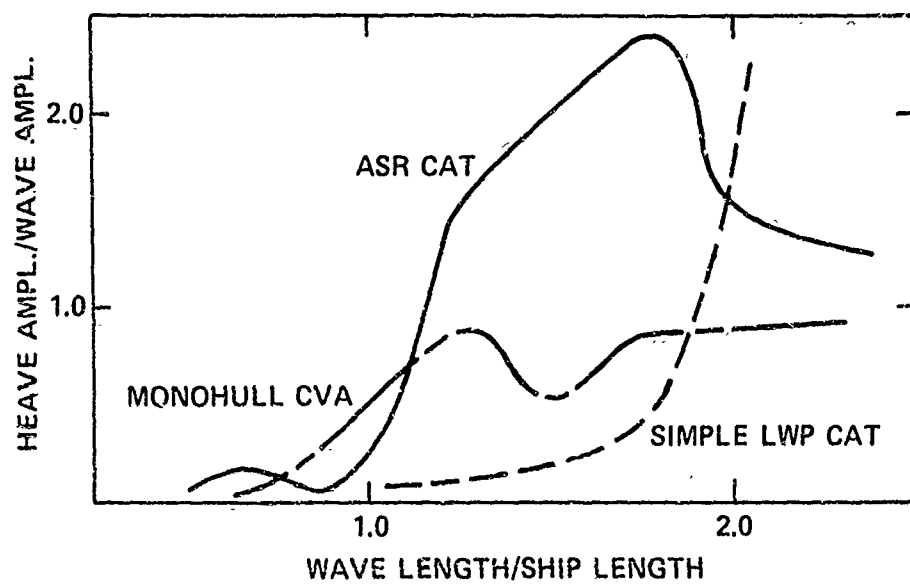


Figure 9 - Heave in Head Waves

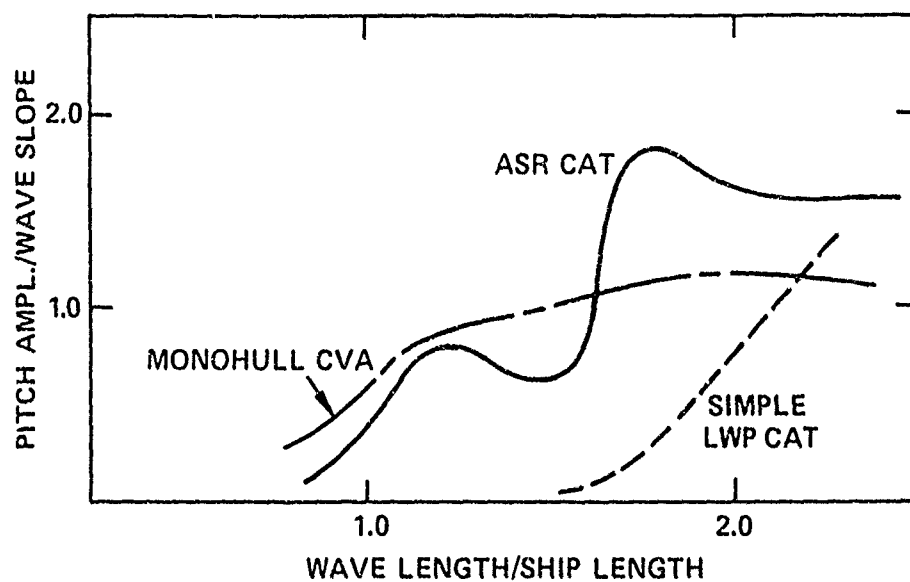


Figure 10 - Pitch in Head Waves

experiments on this improved form demonstrated still less pitch and heave response and, in addition, a shift of resonance to  $\lambda/L = 4$ . The significance of this effect is that it allows substantial latitude in the selection of ship length with little effect on motion response.

Whereas a reduction in waterplane area produces favorable motion effects in head waves, the reverse effect occurs in following waves. Figures 11 and 12 show some degradation in pitch and heave response in following seas. In the tradeoff, however, a net gain is expected since the ship operator may no longer find it necessary to reduce speed in head seas in order to reduce motion.

Comparative roll motions for two catamarans are shown in Figure 13. The amplitude of roll resonance is somewhat higher for the LWP catamaran than for the ASR. The use of flare in the upper portions of the struts and active antiroll or motion-dampening devices may help reduce roll amplitude for the LWP catamaran, but no effort has been expended along these lines.

#### SEA-INDUCED LOADS

Seaway loadings (derived from model experiments in regular seas) on catamaran bridging structures are illustrated in Figures 14 and 15. These loads are a result of hydrodynamic forces on the hulls and do not include inertial effects of bridge mass. These results are shown only for general interest and should not be used as a basis for estimating loads on a particular design. Analytic load prediction methods are now being developed which take many of the catamaran variables into account; they will be available for general use in the near future.

The subject of sea loadings on conventional catamarans has already been covered by Salvesen et al.<sup>5</sup> and by Dinsbacher<sup>6</sup> and will not be

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5. Salvesen, H. et al., "Ship Motions and Sea Loads," Trans. SNAME (1970).

6. Dinsbacher, A.L., "A Method for Estimating Loads on Catamarans Cross-Structure," Marine Technology (Oct 1970).

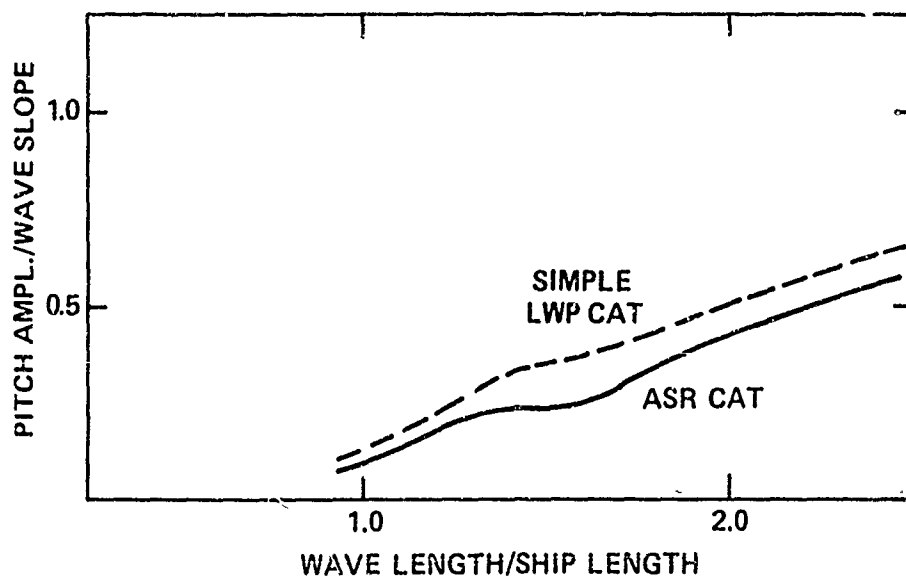


Figure 11 - Heave in Following Waves

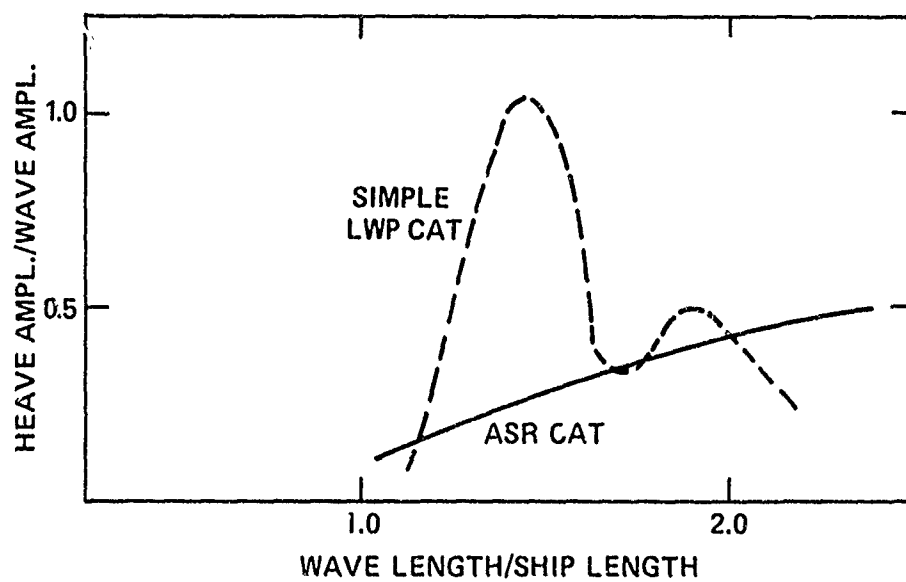


Figure 12 - Pitch in Following Waves



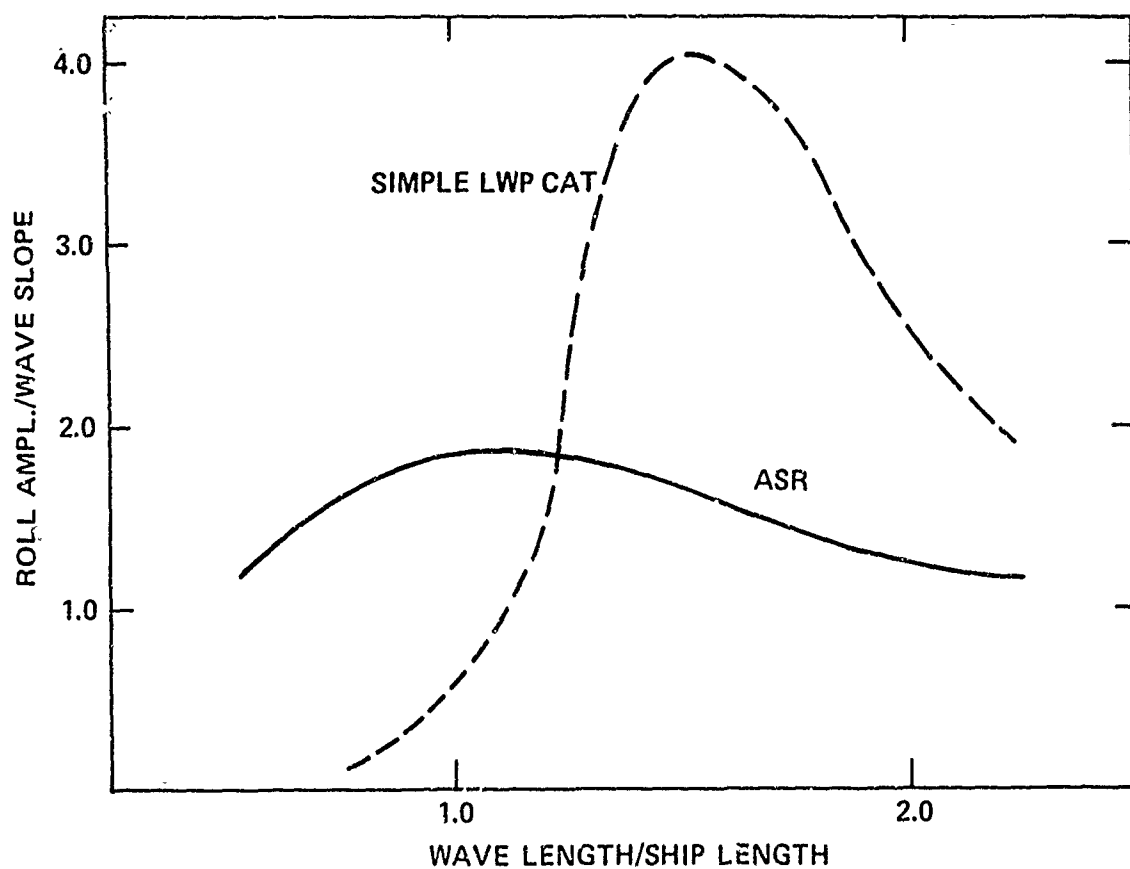


Figure 13 - Roll--Beam Waves at Rest

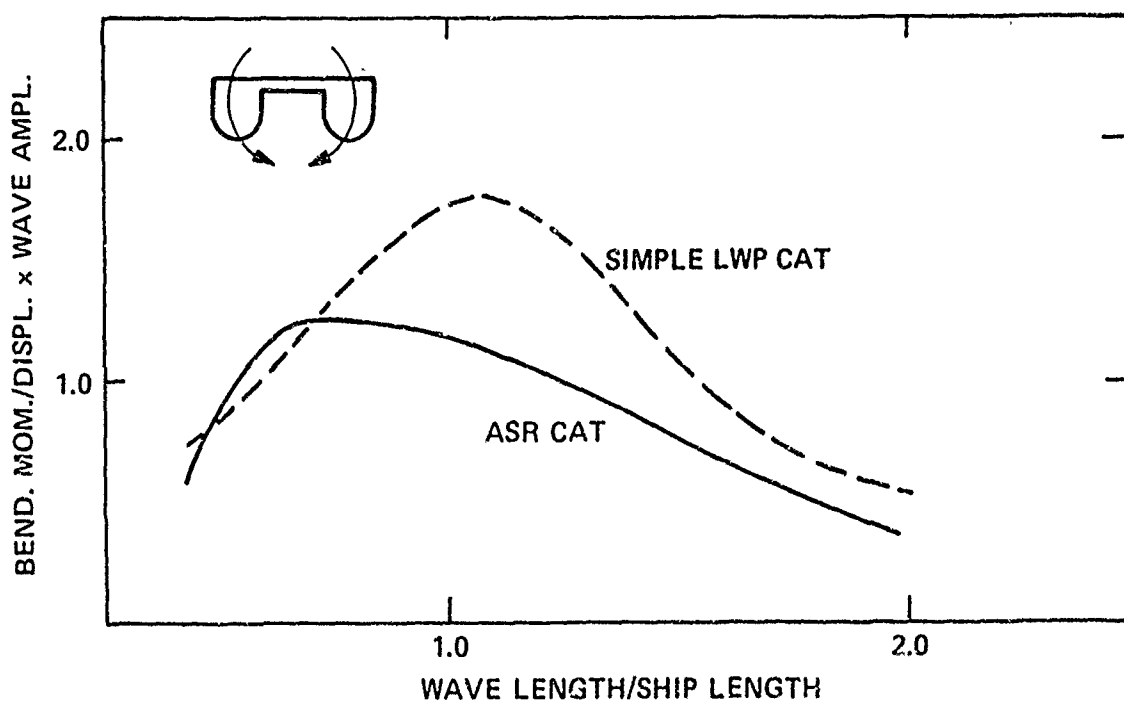


Figure 14 - Vertical Bending--Beam Waves

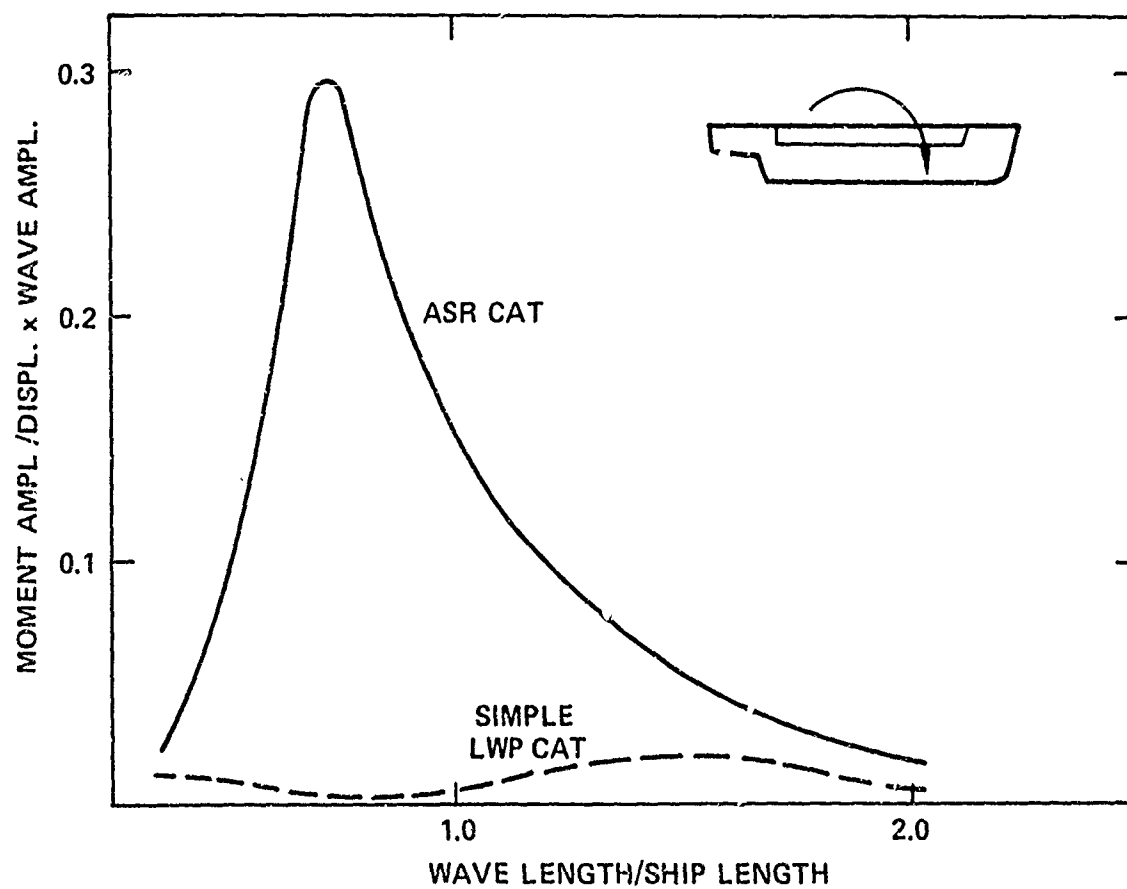


Figure 15 - Torsional Moment--Beam Waves at Rest

discussed here. Of the sea-induced moments applied to LWP catamarans, i.e., longitudinal bending, transverse bending and torsion, the dominant load appears to be in the transverse rather than in the longitudinal direction. In the longitudinal direction, LWP catamarans tend to have a uniform distribution of weight and this, coupled with their reduced waterplane area, produces low hog and sag moments.

Longitudinal moments are resisted by deep structural sections of high modulus, and, consequently, low primary bending stresses are developed. In the transverse direction, however, large moments are resisted by shallow bridging structure sections of relatively low modulus. Stress levels produced by sea-induced loading therefore tend to be greater in the transverse structure than in the longitudinal structure. This behavior will be discussed more fully later. The major point here is that the dominant loading now appears to be in the transverse direction rather than in the longitudinal, contrary to experience with monohulls.

#### SPACE AND WEIGHT

Bond<sup>1</sup> and Leopold<sup>2</sup> have cited increases in catamaran weather deck area and upper hull volume of the order of 40 to 50 percent compared with monohulls of equal displacement. NSRDC studies of aviation ship concepts using the low-waterplane form have demonstrated comparable increases for space above the hangar deck, which was assumed as the lowest deck in the bridging structure. The space in a low-waterplane hull is different from that in a conventional hull, however. The strut sections are narrow, somewhat unaccessible, and generally not well suited as living or working space. These areas would best be used for storage and other secondary purposes. The lower hulls are deep and submarinelike in size and cross section, and they are not very suitable as manned spaces. They would best be used to house main machinery and liquids. By elimination, most arrangement space must be provided in the upper hull, particularly in small, low-waterplane catamarans.

Catamarans, particularly those of the low-waterplane variety, lead one to think of ship space and displacement as independent quantities. For instance, the volume of the upper hull can be altered simply by varying the

hull spacing with no change in form or dimensions of the underwater hull portions. In reality, space and displacement are closely related because volume changes are associated with structural weight changes. Increasing the upper hull volume through increased breadth results in greater structural weight and, with constant displacement, in decreased disposable load. Gaining space through increasing the height of the hull also has its penalties. A rise in the center of gravity occurs in this instance and, with constant waterplane inertia, intact stability is reduced; this may prevent full utilization of the added space. Consideration of stability is as important in the design of an LWP catamaran as for a high-performance monohull ship. The former is designed to provide adequate static stability with minimum waterplane area in order to minimize wave-making resistance and sea-induced motions.

One finds, therefore, that space is not an independent quantity at all; ultimately it is related to payload, stability, powering, and motions. It will be shown below that the disposable load for a catamaran is likely to be less than for a monohull partly because of increased structural weights. All these considerations indicate that the LWP catamaran is a weight-constrained ship and that efforts should be made to reduce fixed and payload weights and densities to a minimum. Catamaran applications have generally involved low payload densities, as in the case of ferries. Air support platforms, escorts, hospital ships, and possibly high-speed, high-value container ships are also good candidates for catamaran application; a fleet oiler is not.

Until very recent years, most surface ships, both commercial and naval, have been weight limited. In the last decade, payloads have become less dense to the extent that most monohull surface ships are now considered to be space critical. The efficient operation of naval vessels is sometimes hampered by lack of adequate space. On a carrier, the spotting and repositioning of aircraft and the packing that occurs on the flight and hangar decks require time and manpower and contribute to inefficiency in operations. Personnel reductions and improvement in weapon reliability, which would result through "all up" weapons stowage are precluded partly

by lack of adequate magazine space. Again, on carriers, crew messing spaces frequently must double as ordnance assembly areas; this degrades habitability and causes crew discomfort.

When dealing with monohulls, space, displacement, and cost have been nearly synonymous. It now appears, however, that the sorely needed additional space can be had without a great sacrifice in performance or cost by using advanced LWP catamarans, provided structural and other weights can be held to tolerable levels.

### STRUCTURES

A major problem area associated with the LWP catamaran has to do with development of efficient structures. There is no large body of empirical information to guide the development of new designs as there is for monohulls. The problem is made more severe by a general lack of information on catamaran loading and by a lack of understanding of the internal load distribution and structural response.

It has been noted that, relative to its displacement, the catamaran will have substantially more enclosed volume and deck area than a monohull. If the structural weight densities estimated and adjusted from monohull practice are applied to catamarans, it is soon evident that hull weights will exceed acceptable values and that payload-carrying capability will be reduced, perhaps to unacceptable levels. The designer is forced to reduce fixed weights wherever practicable, and, accordingly, propulsion installations that use lightweight marine gas turbine engines become essential. Such weight savings are not enough, however, and every effort must be made to further reduce weight by using light but reliable structures.

For reference purposes, structural weight densities for a number of ships and craft are presented in Table 2. The densities reflect weights of the primary hull structure and the total hull volume up to the weather deck. The monohull examples in the table are representative of highly developed lightweight steel structures.

Figure 16 illustrates the relationship between a particular payload item and structural weight. Here, structural weight is traded for fuel

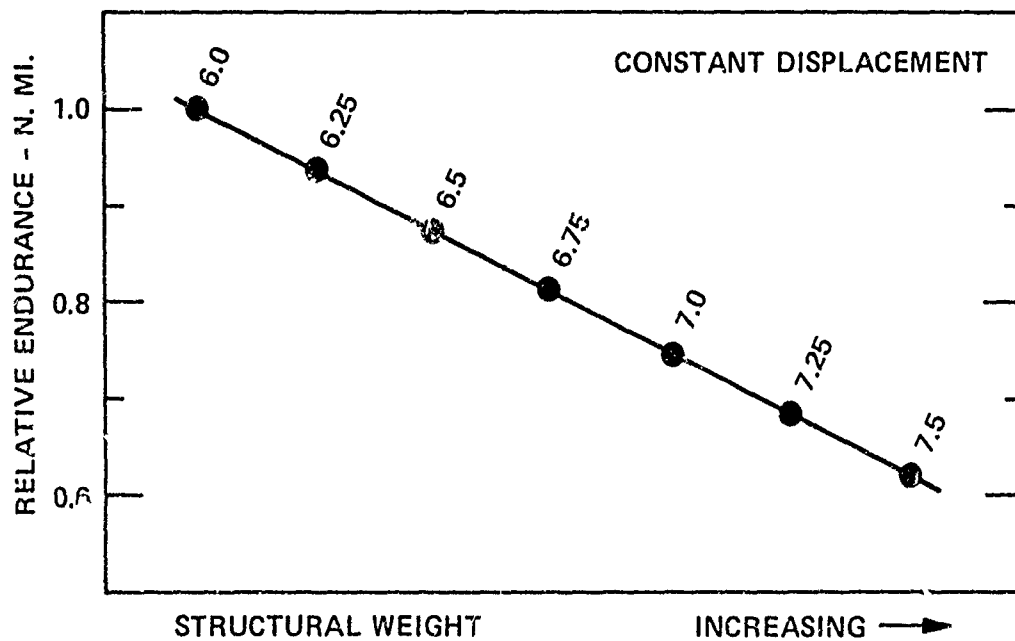


Figure 16 - Effect of Structural Density on  
Endurance LWP Catamaran

(Density is given in pounds per cubic  
foot)

TABLE 2 - DENSITIES OF PRIMARY HULL STRUCTURE

Structure	Density lb/ft <sup>3</sup>
Escort (monohull)	5.7
Helicopter Carrier (monohull)	4.9
ASR (catamaran)	7.5
Hydrofoil (aluminum)	2.3
Landing Ship Dock (monohull)	5.5

weight, and the latter is related to ship endurance. In this particular instance, an increase of 1 lb/ft<sup>3</sup> of structural density produces a 20 percent reduction in endurance.

Based on these considerations, it is apparent that if catamarans are to be competitive with monohulls in payload weight-carrying capability, structural weights must be reduced and held within closely controlled limits. This, in turn, requires reliable prediction of applied loads and precise design in an area where little prior knowledge exists.

As part of a current Navy study, LWP catamaran structures are being investigated to quantify and minimize structural weight. Structural designs in both aluminum and steel are under study; only findings related to the steel structure will be discussed in this report. These findings are preliminary and incomplete, but they are indicative of trends.

The principal design tool is a design computer program<sup>7</sup> developed at NSRDC to optimize the weight of midship section structures according to accepted Navy criteria. The program employs an iterative procedure and selects spacings for supporting structure, panel sizes, and all scantlings suitable for the applied loads. For purposes of this study, the program was modified to design a catamaran transverse section and a longitudinal section through the bridging structure. Use of the program allowed assessment of many more design approaches and structural concepts than would have been possible through manual methods.

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7. Nappi, N.S. and F.M. Lev, "Midship Section Design for Naval Ships," NSRDC Report 3815 (in publication).

Studies have been directed toward a 4300-ton LWP catamaran illustrated in Figure 17. It was learned early that the bridging structure deserved prime consideration inasmuch as more than one-half of the total structural weight was in that structure. Sea-induced loads (which included transverse bending, vertical inertial effects of dead and live loads, axial (transverse) load on the bridge, and slamming on the bottom panels) dominated the structural design in the transverse direction. In contrast, the longitudinal structure was dictated by local loads (dead loads, hydrostatic loads, etc.) with sea-induced loads (i.e., longitudinal bending) contributing little to total stress. For this particular study, the ratio of primary stresses in the transverse structure (on the ship centerline) to those in the longitudinal structure were found to be approximately 10:1. The relative levels of primary stress will vary with different hull geometries; the relative importance of primary loads in these two directions will not.

Thus far, a number of structural arrangements have been examined and their corresponding structural weights and scantlings computed. It was not possible to know *a priori* which structural arrangement would yield the lightest structure. Since an adequate experience base was lacking, a large number of structural arrangements and design assumptions had to be tested. Some insight has been gained on the effect of major variables (hull spacing, bulkhead, web and girder spacing, effective breadth of plating), and suboptimal structural designs have been developed. Figure 17 is representative of the kinds of structure that are currently being examined. This design has an overall structural density of 7.2 lb/ft<sup>3</sup> distributed as follows:

	Density (lb/ft <sup>3</sup> )	Percent of Total Hull Volume
Bridging structure	6.5	58
Struts	8.2	24
Lower hulls	8.0	18

In arriving at this point, however, much has been learned, and directions have been indicated for further reduction of overall structural weight to the goal of 6 lb/ft<sup>3</sup>.



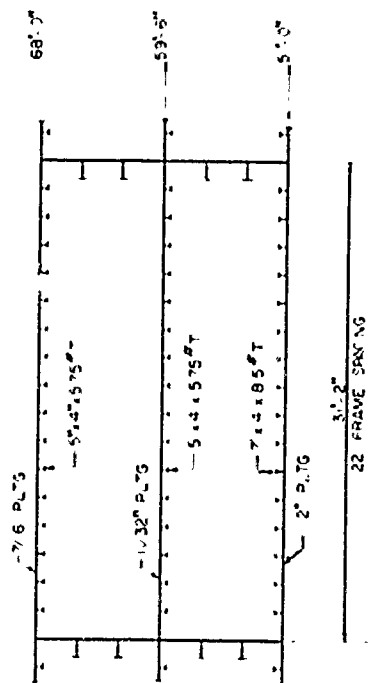
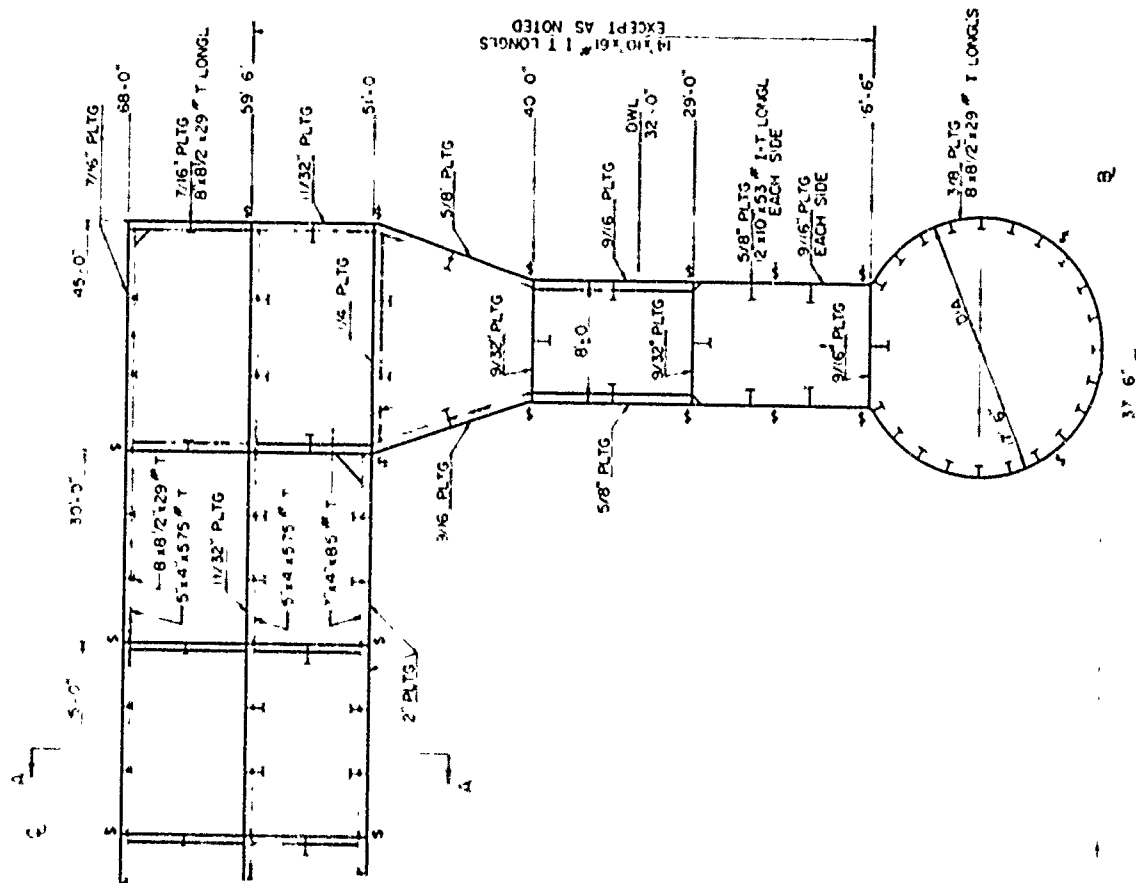


Figure 17 - 4300-Ton LWP Catamaran

Figure 17a - Midship Section

## PROPULSION MACHINERY

The selection of satisfactory propulsion machinery for the LWP catamaran presents some unique problems. As noted earlier, catamarans are competitive with monohull ships in the higher speed regions, but although catamarans may require less power than monohulls of equivalent displacement, installed power will nevertheless be high. Moreover, the selection of propulsion machinery is constrained by weight considerations and by the limited space available in the lower hulls and struts of the LWP catamaran. Because of these factors, most conventional propulsion units are unattractive, and the marine gas turbine is seen as the most applicable power source for this configuration. High-power marine gas turbines (above 25,000 hp) are only now being developed, however, and engines with the desired power rating and operating characteristics are not generally available. Consequently, except for small-to-moderate sized ships, the speeds of LWP catamarans may be limited by the lack of suitable power units.

Studies have recently been undertaken by the Naval Ship Engineering Center (NAVSEC) to assess the problems and practicality of installing a geared gas turbine propulsion system in an LWP catamaran. A controllable reversible-pitch (CRP) propeller was selected for the study in lieu of a reversing gear to reduce gear weight and space requirements. A Pratt-Whitney FT4C gas turbine engine was considered as the prime mover. A preliminary design for each additional element of the propulsion system was undertaken to assess efficiency, physical size, and weight. Double- and triple-reduction gears were examined, as was the planetary gear being developed under Maritime Administration sponsorship.

Turbine and gear arrangement in the lower hull was found to be a fairly major problem with conventional reduction gears. The limited space available in the lower hulls prevented use of optimal propeller speed. Speeds upwards of about 200 rpm were needed to reduce gear sizes to fit available space. A minor reduction in propulsive efficiency was observed, following this course.

Figure 18 illustrates an arrangement for an FT4C engine and a triple-reduction gear. Turbine and gear components and turbine intake and

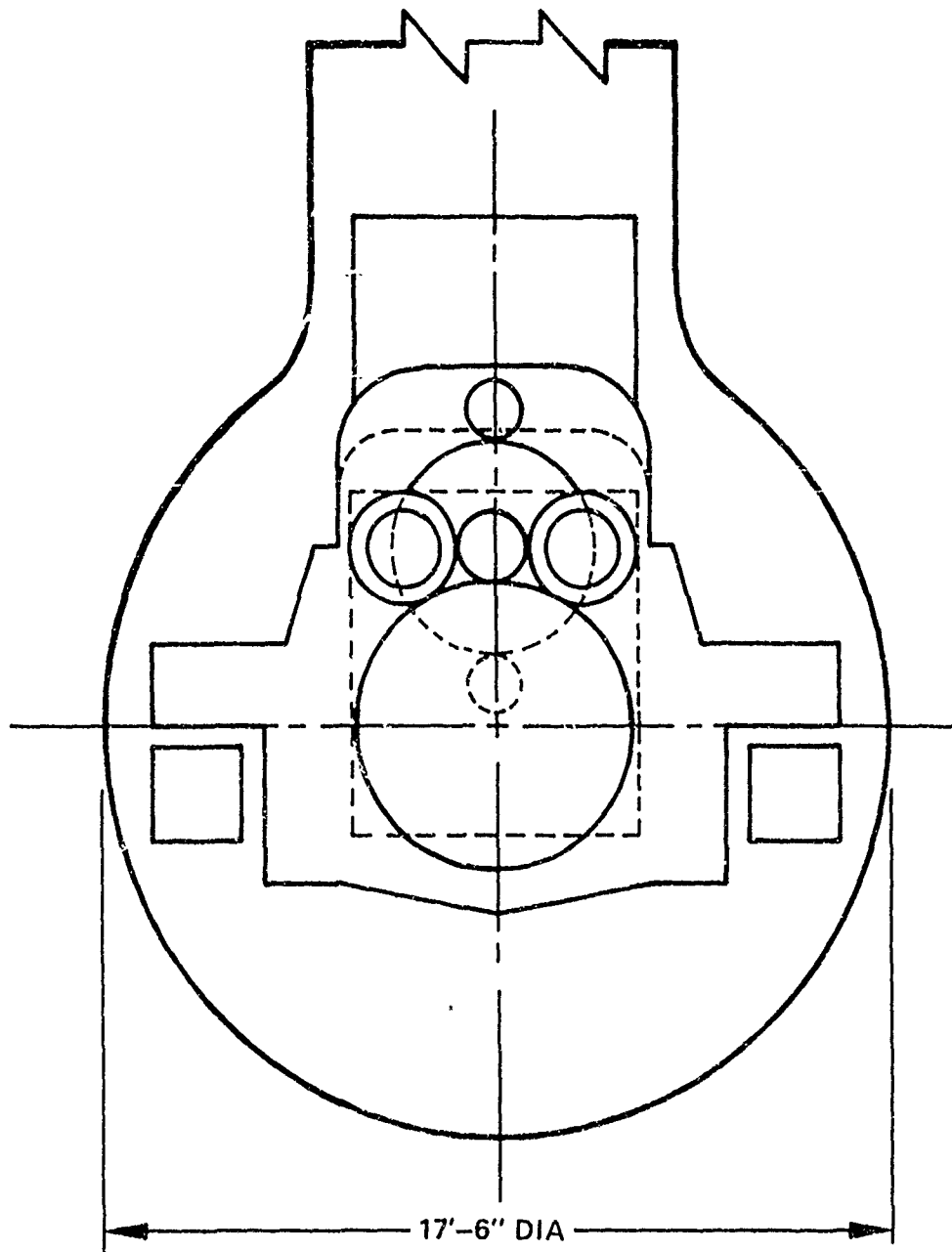


Figure 18 - P.W.FT4C Gas Turbine and Triple Reduction Gear Arrangement in LWP Catamaran

exhaust fit into the area provided, but space is inadequate for through access and secondary components must be arranged farther from the main machinery than is normal practice. Arrangements that utilize carbeurized double-reduction gears overcome the space problem to some extent, but these are most costly. The use of planetary gears produces even greater space savings, but their developmental status is uncertain.

#### INTERACTIVE EFFECTS

The LWP catamaran offers a new and interesting platform option. Although the technology is relatively undeveloped, there is already the prospect of attaining small, high-speed, seaworthy displacement ships.

Some interesting aspects of the LWP catamaran development pertain to the pyramiding of effects. Proper hydrodynamic design, particularly with regard to wavemaking minimization, results in reduced disturbance of the flow around the body, especially that of the free surface. This effect prevails throughout the speed range. Reduced disturbance results in reduced trim and less need for active trim control. Improved flow at the propeller is expected to produce more favorable inflow to the propeller and, therefore, improvements in propulsive efficiency. The reduced waterplane area diminishes motion excitation in a seaway, and so, to a great extent, these propulsion and trim improvements are also achievable in rough water.

Seakeeping investigations have shown the strong dependence of motion response on waterplane area. By reducing waterplane area to a minimal value, the point of pitch and heave resonance has been moved to a wave length/ship length ratio of 4 compared to unity for a monohull ship. For ships of moderate length, this means that resonance is beyond the high energy areas of the seaway, and the occurrence of large ship motions will be low. Because wavemaking is no longer a problem and because the area availability is improved, ships may become shorter while simultaneously providing equivalent space and maintaining excellent powering and seakeeping characteristics.

Transverse static and roll stability should also be mentioned. At design time, there is some flexibility in selecting the waterplane area that will produce the desired transverse characteristics. Thus it is now

possible to tune transverse stability and roll period to a set of requirements without compromising other ship characteristics.

#### NAVAL APPLICATIONS

Several in-depth studies are currently underway to evaluate the LWP catamaran in various naval roles. One possible application is very obvious and has been identified at appropriate Navy levels: that of an air support platform and, more specifically, a future generation Sea Control Ship. When this concept was under study earlier, a conventional catamaran configuration was considered and discarded. Except in large sizes, Concats could not offer the desired speed, payload, or motion characteristics, and the technology at the time could not support either improved characteristics or construction in the size required. Since then development of the low-waterplane configuration holds promise for overcoming many of the disadvantages inherent in the conventional catamaran form. The attributes of the catamaran, and particularly those of the LWP form which contribute to its suitability as a Sea Control Ship, will be discussed briefly.

Space - In addition to being a low-density payload, V/TOL aircraft require a considerable amount of weather deck area and hangar volume. When hangars are below decks, space must be provided for elevators and for spotting and storage areas. Practice has been to locate elevators outboard so that they overhang the hull; there, elevators and the aircraft they transport may be subject to damage from the sea. Monohull platforms have generally provided less space than required for the air complement, and, as a consequence, air readiness has perhaps been less than optimal. Catamarans can provide significantly more deck area than equal displacement monohulls, thus permitting inboard elevators and a larger number of positions for storing, maintaining, and launching ready aircraft.

Ship motions - Ship motions are of prime consideration for air support platforms and undoubtedly have had a major bearing in establishing CVA size. Deck movement sets a boundary on air operations and, in addition, has been cited as a major factor in carrier landing accidents. Compared on an equal length basis with the CV, the LWP catamaran has significantly reduced motion response (see Figures 9 and 10) and should therefore permit extended air operations and improved landing safety.

Vulnerability/survivability - Several considerations here are worthy of mention. There are not likely to be any vital spaces below the waterline other than propulsion machinery. Other spaces may be either void or used for tankage. Below-water damage would result either in limited flooding (which could be counterbalanced by flooding the other hull) and sinkage, or in loss of propulsion power on one side. Tank experiments have shown that catamarans are controllable with power on one side, thereby rendering the ship operable. Widespread flooding, counter-flooding, and sinkage eventually immerses the upper platform. Provided the upper platform is subdivided (and current structural concepts are providing this subdivision), adequate buoyancy and stability are available for continued survivability.

Passive, lightweight missile protection systems for surface ships demand large space allocations. Such space is more readily available in the catamaran ship and, with appropriate engineering, might be incorporated into the subdivision and structural concepts.

Modularity - There has been much discussion but little progress here, partly because modular concepts require accessibility and space. The need is great in air platforms because of frequency modernization of aircraft, avionics, and ordnance and supporting functions. Here again, the inherent configuration of the catamaran, and the LWP catamaran in particular, seems to diminish the problems associated with the application of modular concepts to ships.

These are but some of the characteristics that contribute to the military attractiveness of the LWP catamaran form. Current and future studies, which include manpower utilization, sonar compatibility, daughter vehicle support, logistics support, and compatibility with advanced superconducting propulsion systems, will further document the advantages of this form.

#### FUTURE PROGRAMS

It is hoped that the LWP catamaran can take its place in development along with the hydrofoil, the air cushion vehicle, and the surface effect ship. Research and development funds are in short supply, however, and

cautious optimism is indicated. A joint NAVSHIPS-NSRDC-NAVSEC program is underway to extend the technology, to develop military applicability, and to define technical objectives of an experimental prototype. In the near future, a developmental program may be established which will enable the generation of a broad design data base in all associated technology areas. The most critical area is that of ship structure, and the development program will necessarily include far ranging investigations of loads, structural response, reliability and materials. Such efforts will have only academic utility, however, unless and until the state of technology is demonstrated by at-sea, long-term experiments on a full-scale ship.

#### ACKNOWLEDGMENTS

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